Prolonging Wireless Sensor Network Lifetime Using Routing Protocol

Mohammad Abdus Salam
Department of Computer Science
Southern University
Baton Rouge, Louisiana, USA
md_salam@subr.edu

Kosta Varnavas
Space Systems Department
Electronic Design Branch/ES36
NASA/Marshall Flight Space Center
Huntsville, Alabama, USA
kosta.varnavas@nasa.gov

Bhargava Maddireddy
Department of Computer Science Southern University
Baton Rouge. Louisiana, USA
bhargava_maddiredd00@subr.edu

***Abstract*—Prolonging network lifetime is one of the challenging issues of Wireless Sensor Networks (WSN). Many techniques have been proposed to achieve a longer battery life for the sensor nodes. In this paper, we focus on the routing technique to improve the battery life and extend the network lifetime. Our protocol is based upon the two existing protocols, namely, LEACH (Low-Energy Adaptive Clustering Hierarchy) and PEGASIS (Power Efficient GAthering in Sensor Information Systems). By combining these two basic routing techniques, we propose a new protocol which provides an increase in network lifetime compared to the existing basic protocols.**

Keywords—sensor, wireless, protocol, routing

• Introduction

Applications of wireless sensor networks are expanding tremendously. Wireless sensors are deployed in many places, such as security and surveillance, environmental monitoring, industries, precision agriculture, disaster response, automotive vehicular, health (body area network), underwater sensor networks, space craft, and many more [1], [2]. Moreover, wireless sensor technology will reduce the cost and weight of the space craft [3].These sensor nodes collect useful information from the field. This information could range from audio data, seismic data, and video. These sensor nodes collaborate to perform high level tasks in the deployed environment. Wireless sensor networks may be composed of hundreds or thousands of tiny sensor nodes depending upon the nature of the application and size of the networks. Each sensor node has a sensor as well as computing and communicating capability [4]. These sensor nodes have the capability of communicating among themselves and the base station directly. These sensor nodes are powered by batteries and have limited energy. It is very important that we keep the battery alive as long as possible to enhance the network lifetime. Many network protocols have been developed to increase the network lifetime [5]. The network lifetime has a high impact on the degree of performance and energy efficiency of the network [6]. It is necessary to design communication protocols that will maximize a node's lifetime [7], minimize bandwidth utilization by collaborating among the neighboring nodes and tolerate nodes failure [8].

In this paper, we have considered two fundamental protocols, namely, LEACH and PEGASIS, which are the basic building blocks for our proposed algorithm. In the following sections, we will give a brief description of these two protocols and our proposed protocol.

- Basic Protocols

- *LEACH Protocol*

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol was developed at the MIT Lab by Heinzelman et al. [9]. Since the publication of LEACH, there have been many researchers to enhance it and make it better including the developers of LEACH protocol itself who later published another version of it called LEACH-C (Centralized). There are different versions of LEACH protocol available, such as energy-LEACH and multihop-LEACH [10]. Energy-LEACH improves the cluster head selection method whereas multihop-LEACH improves the communication mechanism between cluster heads and the base station. In [11], Tong and Tang have proposed another improved version of LEACH protocol, called LEACH-B (Balanced). In their protocol, at each round they have introduced two cluster head concepts. The first cluster head is selected based on LEACH protocol and the second cluster head is chosen based on the node's residual energy. This way they have improved the network lifetime compared to LEACH protocol.

LEACH is an adaptive self-organizing clustering hierarchy based protocol. It has two phases of operation, namely, setup and data transmission. In the setup phase of LEACH, sensor nodes are divided into an optimal number of clusters and the member nodes (MN) of each cluster elect their own cluster head (CH) based upon sensor node's energy level in a random fashion. After the cluster setup phase is over, the CH forms a TDMA (Time Division Multiple Access) protocol to communicate among the member nodes of that cluster. Fig. 1 shows about 27 sensor nodes with five clusters. The dark circles represents cluster heads and white circles represent member nodes of a cluster. The CH in a particular cluster rotates among the member nodes of that cluster after a certain round of data transmission. The CH performs data aggregation before it transmits to the base station (BS) to minimize energy dissipation and maximize network lifetime. After a round is over, the cluster is reformed among the remaining sensor nodes in a similar manner and the process continues until all the nodes in the network die.

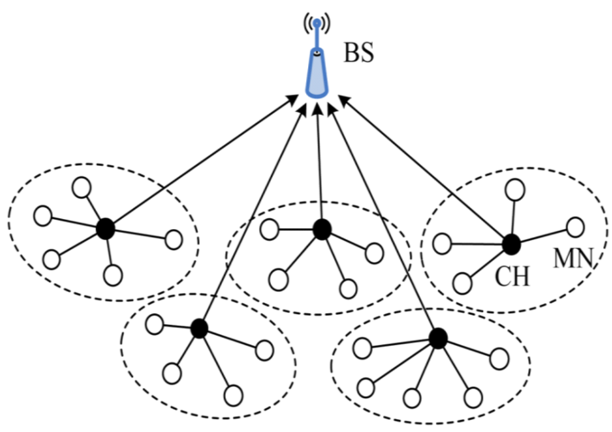

Fig. 1. LEACH protocol architecture [12]

LEACH protocol outperforms direct communication protocol significantly. In direct protocol, nodes transmit data directly to the base station. Therefore, nodes farther from the base station die quickly compared to the nodes closer to the base station because of the energy dissipation due to longer distance.

- *PEGASIS Protocol*

PEGASIS (Power Efficient GAthering in Sensor Information Systems) is proposed after the LEACH protocol to improve the network lifetime [13]. Since the development of PEGASIS, many scientists have been working to improve PEGASIS protocol. There are various improved versions of PEGASIS available. In [14], Li et al. have proposed an ant colony algorithm to form the chain instead of greedy algorithm. Feng et al. have proposed another improved version of PEGASIS, which they named IEEPB (Improved Energy-Efficient PEGASIS-Based Protocol) [15]. IEEPB protocol assigns each node a weight and uses weighting mechanism to select the transmitter node. They claimed that their modified version balances energy consumption and improves network lifetime compared to PAGASIS protocol.

Now, let us provide a brief description of PEGASIS. In each round, all sensor nodes' data needs to be collected and transmitted to the base station to make a decision about the deployed environment. In PEGASIS, the sensed information of the deployed environment is gathered by forming a chain among the sensor nodes (Fig. 2). The chain formation is done by using the greedy algorithm where each node will receive and transmit data to the nearest neighbor. It is assumed that all nodes have the global knowledge of the network and the base station has the knowledge about the geographic location of each sensor node. The farthest node from the base station will be the first node in the chain, i.e. the chain formation starts from the farthest node. Each node performs data fusion with its own sensed data and received data from the neighbor. The fused data is then transmitted to another neighboring node. Each node takes turns being a transmitter to the base station.

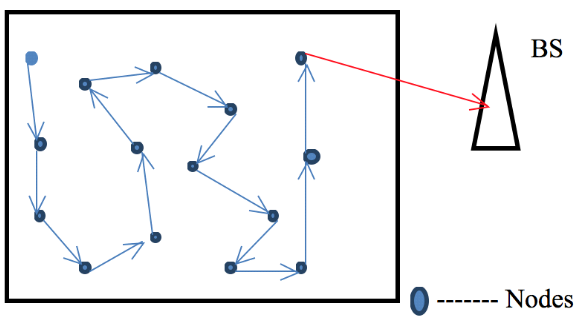

Fig. 2. PEGASIS protocol architecture

This way energy dissipation is distributed among the nodes. Priority is given to the higher energy nodes to be a transmitter. This way the transmission distance is minimized. PEGASIS protocol outperforms LEACH by approximately 2x the number of rounds when 1%, 20%, 50%, and 100% of nodes die for a 50m x 50m network [13].

- Proposed Protocol

- *Architecture of the Proposed Algorithm*

Our proposed algorithm is based on the LEACH and PEGASIS algorithms. In the proposed algorithm, as shown in Fig. 3, the entire network is divided into clusters based on the LEACH protocol and in each cluster the nearest node to the base station is considered as the cluster head. The white circles represent member nodes and the black circles represent a cluster head. In each cluster the base station will calculate the distance of each node and the chain formation will start from the farthest node in cluster based on the PEGASIS protocol. The following steps describe the proposed algorithm.

Step-1: It is assumed that BS has the knowledge of the entire network and it will calculate the distance from each node in the network.

Step-2: Formation of clusters is based on the LEACH protocol.

Step-3: In each cluster, the node that is nearer to BS will be the cluster head.

Step-4: The base station will calculate the distance of each node in the cluster and the farthest node in the cluster is considered the initial node and from there the chain formation is done based on PEGASIS protocol.

Step-5: Once all the chain formation is done in each cluster, the BS will calculate the distances of all the cluster heads and the farthest cluster head is selected as the initial node, and from that cluster head, the chain formation for the neighboring cluster heads is based on PEGASIS protocol.

Step-6: The final cluster head in the chain will be considered as a transmitter and send the data to the BS.

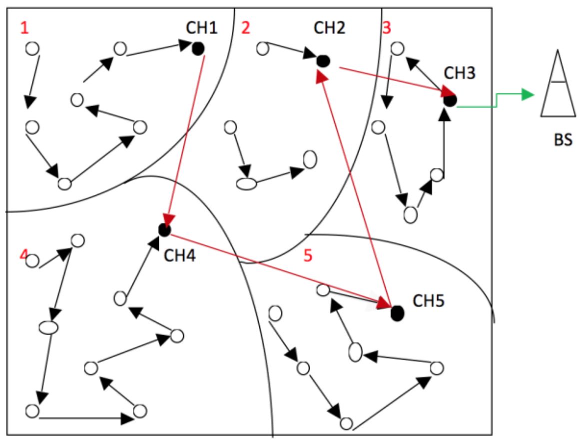

Fig. 3. Proposed protocol architecture

As shown in the Fig. 3, the entire network is divided into five clusters based on the LEACH protocol. The cluster heads CH1, CH2, CH3, CH4, and CH5 are chosen based on the distances from the base station. In each cluster the formation of the chain is based on the greedy algorithm, which we use in PEGASIS. The cluster head will be the base node in the chain in each cluster. First, the chain formations are done in each cluster. Second, the base station will calculate the distances of each cluster head and the farthest node is chosen as the initial node and from there chain formation between each cluster head is done, i.e., in our case, CH1 is the initial node and the chain forms like this: CH1 to CH2, CH2 to CH3, CH3 to CH4, CH4 to CH5. The transmitter node, CH5, will transmit the data to the base station.

- *Simulation of the Proposed Algorithm*

In our simulation, we have considered 60 sensor nodes to analyze the network performance. A Java program is coded according to the proposed algorithm. The base station is located at (100, 100) location. Initially, all the nodes in the network will have the same energy. The following figures (Fig. 4, 5, and 6) show the status of the nodes at their different rounds. Fig. 4 displays the initial set up and (x, y) location of all 60 sensor nodes. They are all alive at this round of the network. The orange color represents alive nodes and the green color represents a dead node.

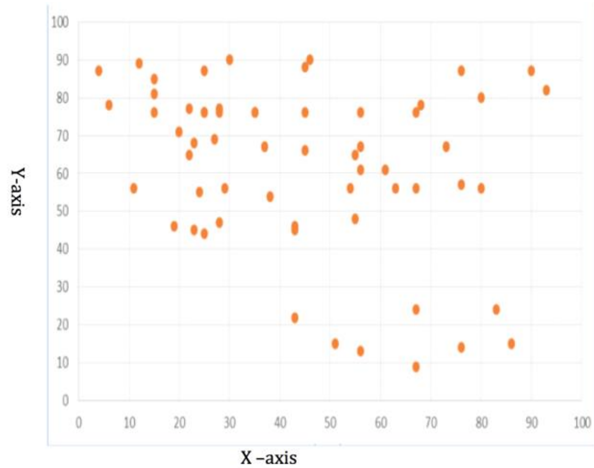

Fig. 4. Nodes status at the beginning

After the 10 rounds, we see some of the nodes are dead and most of them are still alive (Fig. 5).

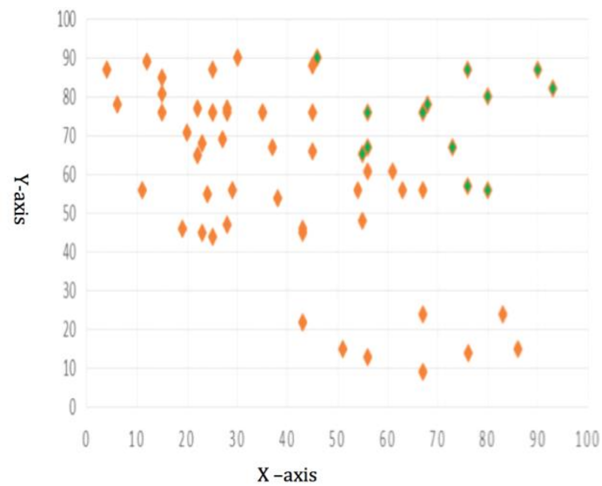

Fig. 5. Nodes survival status at round 10

After the 30th round, we found that most of the nodes are dead (Fig. 6).

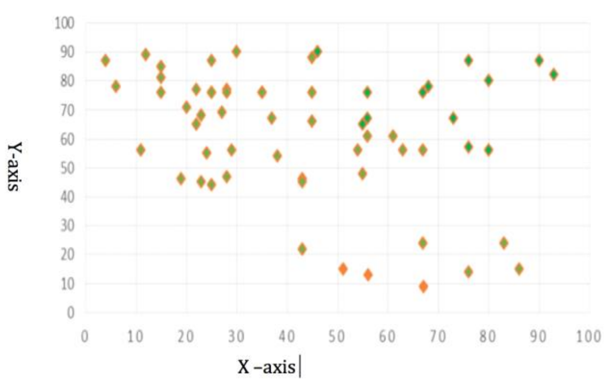

Fig. 6. Nodes survival status at round 30

Fig. 7 represents the graphical representation of all the nodes, at which round it dies, and the graph is plotted based on the simulation results. The graph is drawn by considering all 60 nodes on the x-axis and number of rounds they can communicate with the base station on the y-axis. For example, node number 60 dies at round 29 and node number 41 dies at round 9.

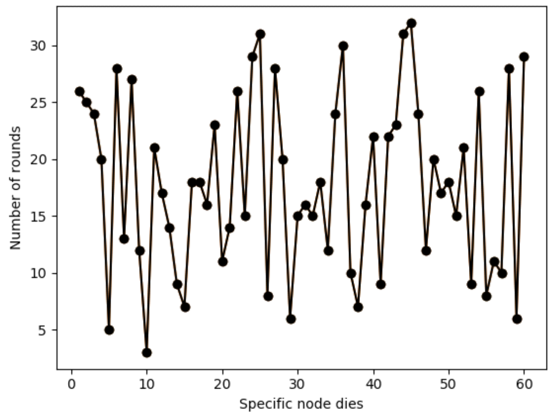

Fig. 7. Nodes' survival status at a specific round

Table 1. Node's location and status data

#	Loc	Dist	Pro	Peg	#	Loc	Dist	Pro	Peg
1	76,14	89.3	26	12	31	54,56	63.7	16	3
2	12,89	88.7	25	15	32	43,46	78.5	15	12
3	15,85	86.3	24	20	33	25,87	76.1	18	20
4	67,24	82.9	20	3	34	67,56	55	12	25
5	80,56	48.3	5	2	35	15,76	88.3	24	7
6	25,44	93.6	28	3	36	19,46	97.3	30	15
7	45,66	64.7	13	8	37	56,76	50.1	10	9
8	28,47	89.4	27	25	38	76,87	27.3	7	2
9	45,76	60	12	7	39	23,45	94.6	16	8
10	73,67	42.6	3	5	40	20,71	85.1	22	6
11	29,56	83.5	21	25	41	68,78	38.8	9	1
12	27,69	79.3	17	25	42	38,54	77.2	22	8
13	37,67	71.1	14	3	43	23,68	83.4	23	3
14	56,67	55	9	4	44	67,9	96.8	31	20
15	46,90	54.9	7	2	45	56,13	97.5	32	20
16	22,77	81.3	18	5	46	25,76	78.7	24	4
17	11,56	99.3	18	9	47	45,88	56.3	12	8
18	25,76	78.7	16	20	48	28,77	75.6	20	2
19	22,65	85.5	23	15	49	35,76	69.3	17	13
20	56,61	58.8	11	7	50	30,90	70.7	18	6
21	61,61	55.2	14	20	51	55,48	68.8	15	3
22	24,55	88.3	26	4	52	28,76	75.9	21	17
23	35,76	69.3	15	4	53	55,65	57	9	10
24	4,87	96.9	29	25	54	43,45	79.2	26	13
25	51,15	98.1	31	12	55	80,80	28.3	8	8
26	67,76	40.8	8	5	56	6,78	96.5	11	5
27	43,22	96.6	28	25	57	76,57	49.2	10	9
28	83,24	77.9	20	10	58	86,15	86.1	28	12
29	90,87	16.4	6	1	59	93,82	19.3	6	4
30	63,56	57.5	15	13	60	15,81	87.1	29	10

Table 1 shows the complete data of the 60 sensor nodes. The column header indicated by # represents the node number. We have a total of 60 nodes with labeled from #1 through #60. The "Loc" columns represent the (x, y) coordinates of each sensor node. In our simulation, we have considered that sensor nodes are not mobile, i.e. they remain in the same location until they die. The "Dist" columns show the distance of a sensor node from the base station, i.e. how far is that node located from the base station. The "Pro" columns display the number of rounds at which a particular node is dying for the proposed algorithm. The "Peg" columns demonstrate the number of rounds after which a sensor node dies for the PEGASIS algorithm.

- *Simulation Results*

Table 2 shows the simulation output of the proposed and the PEGASIS algorithms. Here we see that all nodes are dead at round 26 for the PEGASIS algorithm, whereas, the proposed method survives longer. All nodes are dead at round 32 for the proposed method.

Table 2. Comparison of node status for the proposed and the PEGASIS

Round	Proposed	PEGASIS
0	60	60
2	60	54
4	59	43
6	54	38
8	50	30
10	45	24
12	40	20
14	37	17
16	31	15
18	27	14
20	24	9
22	19	9
24	14	9
26	10	0
28	6	0
30	3	0
32	0	0
34	0	0
36	0	0
38	0	0
40	0	0

After all the nodes in the network die, then we can calculate the lifetime of the network based on the number of rounds the data has been communicated between nodes and the base station.

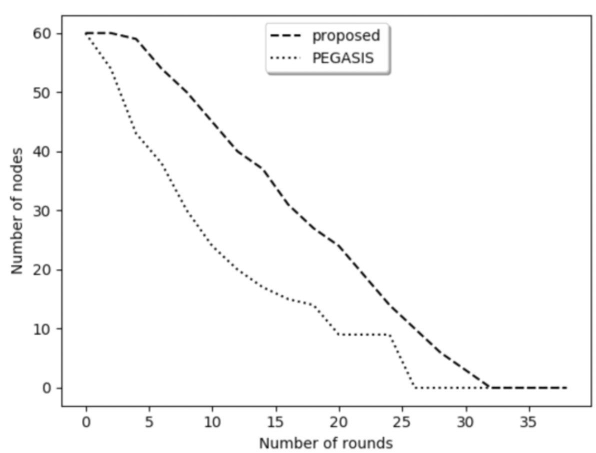

Fig. 8. Network lifetime comparison between the proposed and PEGASIS algorithms

Fig. 8 displays the number of nodes that survive versus the number of rounds at which they die. It compares between the proposed algorithm and the basic PEGASIS algorithm. As we see in the above graph, all the nodes are dead after 26 rounds of data transmission to the base station for the PEGASIS algorithm.

The proposed algorithm staying a bit longer than the PEGASIS i.e., the sensor network dies at round 32. In comparing these two algorithms, we found that the proposed algorithm prolongs the overall network lifetime more than the basic PEGASIS algorithm. Also, the proposed algorithm is more energy-efficient compared to the LEACH and PEGASIS.

In Fig. 8, we have compared between the proposed algorithm and basic PEGASIS. Since PEGASIS outperforms LEACH, we did not include LEACH in the comparison.

• Conclusion

In this paper, we describe the proposed algorithm along with the other two algorithms, namely, LEACH and PEGASIS. LEACH is a cluster based hierarchical algorithm and PEGASIS is a chain-based algorithm. Many researchers around the globe have modified both of these algorithms. In this paper, we combined the concepts of these two algorithms and proposed a modified version that compares favorably with the existing algorithms. Since the lifetime is one of the most important factors to be considered while designing the sensor networks, our proposed algorithm outperforms other two algorithms in terms of network lifetime. The proposed algorithm has an improvement of 7% in the lifetime of the network over PEGASIS. Hence, the proposed protocol has better performance in terms of lifetime than the existing basic protocols according to the simulation results conducted in this research.

In this research all the nodes are considered non-mobile. The locations of the nodes do not change once they are deployed. In many practical applications, these nodes are dynamic, i.e. mobile. In the future, we can consider the mobility issue of sensor nodes while forming the clusters and chain. In this research, we also do not consider the network delay. As further research, we can consider the network delay to compute network performance and energy-efficiency. Aerospace vehicles operate in an extremely harsh environment with temperatures ranging from cryogenic to very high [3]. Our future research direction could include batteries that may operate adequately in these extreme environments.

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